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ABSTRACT

Designed to develop procedures and acquire information to help decision-makers establish policies for the use of microcomputers for computer-assisted instruction (CAI), this study involved the following steps: (1) a school-based research project was conducted to determine the costs and effects of microcomputer-assisted instruction; (2) an analytical procedure for assessing the cost-effectiveness of microcomputer-assisted instruction and traditional instruction was developed; and (3) this analytical procedure was applied to the costs and effects obtained in this study. Subjects were 41 grade 3 students and 38 grade 5 students in a rural area of Saskatchewan, Canada, who were given a pretest to measure mathematics ability, mathematics attitude, and computer literacy. Students at each grade level were then randomly assigned to two groups: the control group received traditional mathematics instruction, and the experimental group received adjunct microcomputer-assisted instruction. On the basis of the findings, it was concluded that the use of supplementary microcomputer-assisted instruction enhanced both the mathematics skills and level of computer literacy of the subjects in the experimental group; there was no significant difference between the effects of the two treatments on student attitudes toward mathematics; and the cost of adjunct microcomputer-assisted mathematics instruction was lower than previous estimates of costs for laboratory-based CAI and more cost-effective than traditional mathematics instruction in relation to the desired outcomes. Seventeen tables are included, 25 references are listed, and additional data are appended. (MES)

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COSTS, EFFECTS, AND UTILITY OF MICROCOMPUTER-ASSISTED INSTRUCTION

David E. Hawley
J. Dexter Fletcher
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Technical Report, Number 1

November 1986

Center for Advanced Technology in Education

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ABOUT CATE

The Center for Advanced Technology in Education (CATE) is a consortium of university-based, community, and state organizations with an interest in the use of advanced technology in schools. The educational use of computers is a primary focus of the Center's activities.

Opened in 1983, CATE is the site of both preservice and inservice training for educators and a field-based research and development program investigating a variety of advanced and interactive instructional technologies and their implications.

Members of the CATE Council and the CATE network are widely scattered across Oregon. They include school districts, state colleges, community colleges, extension services, and the State Department of Education. Housed in the CATE facility at 1787 Agate is the ERIC (Educational Resources Information Center) Clearinghouse on Educational Management, the International Council for Computers in Education (ICCE), the Instructional Technology (IT) Laboratories, and the Career Information System (CIS). CATE also includes a resource library and facilities for classes and workshops on the use of computers in education.

For more information about CATE, write to Center for Advanced Technology in Education, 1787 Agate, Eugene, Oregon 97403.

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FOREWORD

Widespread availability of microcomputers in schools is a very recent development. As a genuine innovation, this change initially raises both enthusiasm and skepticism among participants and observers of the learning enterprise. Pertinent facts and appropriate methods for interpreting them are needed by the teachers, instructional designers, administrators, parents, and school board members who decide about schooling in America. The Center for Advanced Technology in Education was created for just such purposes--to enable university and school personnel to join in evaluating, understanding, and deciding about the use of technology in education.

Cost-effectiveness analysis is a tool that can help us understand one educational facet of the computer revolution. It is appropriate that this study of costs, effects, and utility is the first Technical Report published by the Center. We hope it will be both stimulating and useful, and we look forward to sharing other technical reports that will also advance the understanding and appropriate use of technology in education.

David E. Hawley, on whose doctoral dissertation this report is based, is superintendent of the Kindersley School District in Saskatchewan, Canada. J. Dexter Fletcher, formerly an associate professor of computer and information sciences at the University of Oregon, is a research analyst with the Institute of Defense Analysis in Alexandria, Virginia. Philip K. Piele is professor of educational policy and management and director of the ERIC Clearinghouse on Educational Management at the University of Oregon.

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Chapter 1

INTRODUCTION

Background

Much has been written in recent years about the new wave of technology. At the crest of this wave is the electronic digital microcomputer, which is radically changing the way we process information. Yet the electronic computer is not new. The first digital computer was introduced to North America in 1945. What is new is the size and the price of the computer. The rapid growth in technology--from vacuum tubes, to transistors, to integrated circuits on silicon chips--has progressed to the point where computing power previously housed in a large climate-controlled room now fits easily inside a desk-top computer. In the last five years, the cost of computing has dropped enough to enable every segment of society to access computer technology.

Few school boards and school administrators are, as yet, familiar with the issues surrounding these advances in microcomputer technology. However, in the present economic climate, the public is holding boards and administrators more accountable than ever for the decisions they make. At the same time, members of the public, teachers, and students are clamoring for more use of computers in schools. Frequently they cite reviews of research literature, such as the one by Forman (1982), who concluded as follows:

1. The use of computer-assisted instruction (CAI) either improved learning or showed no difference when compared with traditional classroom approaches.
2. The effect on achievement occurred regardless of the type of CAI used, the type of computer system, the age range of students, or the type of instrument used to make the measurements.
3. When CAI and traditional instruction are compared, equal or better achievement using CAI is obtained in less time.
4. Students have a positive attitude toward CAI, frequently accompanied by increased motivation, attention span, and attendance in courses.
5. The bulk of studies showing CAI to be effective have concerned the use of adjunct CAI in which the classroom teacher was readily available. (p.38)

However, most of the research covered by Forman and other recent reviewers did not entail the use of microcomputers for CAI delivery. Instead, these studies have focused on minicomputers and mainframe systems. The future of computing in schools is most probably tied to the microcomputer. Thus research is needed to determine whether microcomputer-based instruction can be educationally effective under typical conditions of use. A few such studies have already been conducted.

Microcomputer Effectiveness

Dorsey and Burleson (1982) reported that five microcomputers were used to provide second- and third-grade children with fifteen minutes per week of drill and practice in mathematics using the *Milliken Math Sequence* software package. Students' scores on the Science Research Associates (SRA) standardized mathematics test indicated that during the ten months of the program second-grade students increased an average of 1.80 grade equivalents; for students in grade 3, the mean increase was 2.10 grade equivalents.

Trifiletti, Grith, and Armstrong (1984) compared CAI instruction in mathematics using microcomputers with traditional instruction for learning disabled students. Students in the CAI group received forty minutes of microcomputer-based instruction each day for the school year, whereas the control group received an equivalent amount of traditional instruction. The grade equivalent gain in mathematics for the CAI group was 0.8 years, whereas the comparable grade equivalent gain for the control group was 0.3 years.

Easterling (1982) investigated the effects of microcomputer CAI on the mathematics achievement of fifth-grade students using the *SRA Computer Drill and Instruction* software package. Students were exposed to two fifteen-minute sessions per week of CAI for sixteen weeks. No significant differences in achievement were found between the CAI students and non-CAI control group. Easterling recommended that future studies gather qualitative data concerning student attitudes and quantitative data concerning student knowledge of the computer.

Finally, Steele, Battista, and Krockover (1984) compared the effect of microcomputer CAI drill and practice with that of a paper-and-pencil individualized drill-and-practice program on fifth-grade students' mathematics achievement and computer literacy. The CAI program used the *Milliken Math Sequences* software to provide instruction for ten minutes twice a week over nine months. It produced significantly greater achievement in mathematics computation than did a control program of similar duration. No differences between the groups on gains in concept or problem-solving scores were noted, however. The CAI group showed a significantly greater gain than did the control group in both the affective and cognitive domains of computer literacy as measured by the *Minnesota Computer Literacy and Awareness Assessment.* The researchers recommended that further studies examine the effect of microcomputer drill-and-practice CAI on students' computer literacy.

Cost Effectiveness

It is not enough for decision-makers to know that a new instructional capability is effective. Many effective instructional capabilities are not used because their cost is prohibitive. Alternatively, many instructional capabilities are used despite their limited effectiveness because their cost is minimal. In short, to determine the desirability of an instructional capability, a decision-maker must know

something about its cost-effectiveness.

Cost-effectiveness analysis is one of a family of analysis activities known generally as systems analysis and based upon work in the wartime field of operational analysis (Beilby 1977, Quade 1971). In current usage, the concept of systems analysis encompasses several specific kinds of analysis activity, including cost-benefit analysis and cost-utility analysis in addition to cost-effectiveness analysis. Of these, cost-benefit analysis is the least appropriate for educational program evaluation because it requires that all outcomes be expressed in common terms, such as dollars. However, cost-effectiveness and cost-utility anal[illegible]es can assist educational decision-makers in choosing among alternative programs in order to select and organize school resources more effectively.

Some literature designed to assist researchers to use cost-effectiveness analysis in program evaluation does exist. Alkin (1970) provides an early chapter advocating its use in the evaluation of instructional programs. Thompson (1980) discusses the use of cost-effectiveness in his volume on benefit-cost analysis in evaluation. Levin (1975) provides a sound general introduction to the topic, followed by an instructional analysis of specific applications in educational evaluation (Levin 1981).

Levin (1984) performed a cost-effectiveness analysis of CAI by estimating costs and applying meta-analysis techniques to CAI effects obtained from a number of earlier studies. Although this analytical technique lacks the precision that could be obtained through an actual experiment, the "ingredients method" Levin has developed for determining the costs of a CAI intervention provides a logical basis for cost analysis.

Using his method, Levin arrived at a cost of $119 per year to provide one student with computer-assisted instruction for ten minutes per day using a minicomputer system (Levin 1984). Piele, using the same method to determine the cost of a networked microcomputer system, estimated the cost of a similar service to be $121 per year per student (Levin 1984).

Utility

Often the problem of choosing among alternatives involves more than the determination of relative effectiveness and efficiency. The decision is also guided by such issues as equity, social impact, and the decision-makers' values. In such cases, the most appropriate technique to employ is cost-utility analysis. In contrast, cost-effectiveness analysis does not involve explicit consideration of the decision-maker's judgment of program value or worth. The measurement of utility assigns a numerical valuation of the desirability each possible outcome has for each decision-maker. When utility measures are combined with cost-effectiveness analysis, the resulting decision process more closely reflects the desires of the decision-maker. Utility analysis is particularly useful for educators who wish to assess the cost-effectiveness of an intervention for producing a variety of student outcomes and to establish the value that various participants in the decision process place on each outcome.

Purpose of the Study

This study was designed to develop procedures and acquire information that will help decision-makers establish policies regarding the use of microcomputers for computer-assisted instruction. The study involved the following steps:

1. Conducting a school-based research project concerning the costs and effects of microcomputer-assisted instruction.
2. Developing an analytical procedure for assessing the cost-effectiveness of microcomputer-assisted instruction and traditional instruction.
3. Applying the analytical procedure to the costs and effects obtained in the school-based project to inform a decision regarding implementation.

The following key terms are defined to clarify their meaning in the study:

1. *Adjunct computer-assisted instruction* is defined as the use of a computer and a computer software program to supplement the learning situation in the classroom--under the direction of the classroom teacher.
2. *Cost-effectiveness* is the cost per unit of outcome of any activity.
3. *Cost-utility* is the cost per unit of outcome of any activity when the utility (value) of the outcome compared to other outcomes is considered.
4. *Primary computer-assisted instruction* is the use of a computer and a computer software program to provide instruction without the need for a teacher.
5. *Utility* is the value or usefulness of something--as rated by respondents on a numerical scale.

Chapter 2

METHODS AND PROCEDURES

Setting for the School-Based Study

Westberry Elementary School, in Saskatchewan, Canada, serves 422 students (K-7) with a professional faculty numbering 20. About 73 percent of the students live in the town of Kindersley, with a population just over 5,000. The remaining 27 percent of the students live on farms in the rural area surrounding Kindersley. The school is ideally suited for comparing the effect of two treatments on a group of students as there are at least two classrooms of students at each grade level.

Prior to the 1984-85 academic year, Kindersley schools had implemented computer literacy programs for junior high school students and computer science programs for high school students. However, no microcomputers were being used in elementary school. Beginning in October 1984, one microcomputer was placed at the disposal of the elementary school staff. Care was taken to avoid contamination of the project by using this microcomputer only with students not involved in this study.

Research Design

The study, involving students in grades 3 and 5, used a pretest-posttest control group design. All students were given a pretest to measure mathematics achievement, mathematics attitude, and computer literacy. Then students in each of the two grade levels were randomly assigned to two groups. The control group at each grade level (3TI and 5TI) received traditional mathematics instruction, whereas the experimental groups at each grade level (3CAI and 5CAI) received adjunct microcomputer-assisted mathematics instruction. Following these treatments each group was given a posttest to measure mathematics achievement, mathematics attitude, and computer literacy. There were twenty-one students in group 3TI, twenty in group 3CAI, nineteen in group 5TI, and nineteen in group 5CAI.

The research design can be represented as follows:

Control Group (TI)	01—X1—02
Experimental Group (CAI)	01—X2—02

In this representation, the observations and treatments are as follows:

Observations

01--Pretests

1. Canadian Tests of Basic Skills Mathematics Subtests
2. Survey of School Attitudes
3. Computer Literacy Test

02--Posttests

1. Canadian Tests of Basic Skills Mathematics Subtests
2. Survey of School Attitudes
3. Computer Literacy Test

Treatments

X1--Traditional Mathematics Instruction
X2--Adjunct Microcomputer-Assisted Mathematics Instruction

Procedure

The three pretests were administered in January 1985 prior to random assignment of students to treatment groups. The three posttests were administered in May 1985. Both treatments were carried out for 71 school days between January and May 1985. A description of each treatment group follows.

Grade 3 Traditional Mathematics Instruction (3TI)

Students in the 3TI group were taught mathematics using the instructional delivery traditionally used by the teacher. Mathematics classes were scheduled for sixty-six minutes per day but took place on only five days during each six-day cycle. This resulted in an average class time of fifty-five minutes per day.

The textbook used was *Series M Mathematics SI Edition* (Forbes and Thoburn 1980). At the beginning of each period, the teacher taught a lesson of twelve to eighteen minutes duration either dealing with new work or reviewing concepts previously taught. This was followed by drill-and-practice time during which students did problems from the textbook (either with paper and pencil or using the chalkboard), used teacher-constructed drill sheets or coloring sheets, worked with materials such as flash cards or clocks, or played oral math drill games.

Grade 3 Adjunct Microcomputer-Assisted Mathematics Instruction (3CAI)

Mathematics instruction for this group was provided by the same teacher who taught the 3TI group. This teacher was provided with two hours of training in the use of microcomputers for instructional purposes, but had no other prior knowledge of computers or computing. Instruction was essentially the same as that for the 3TI group with one major exception. Each student received, during the sixty-six-minute mathematics period, twelve minutes of mathematics drill and practice using a microcomputer and *Milliken Math Sequences* software (Milliken Publishing Company 1980). This occurred five times in each six-day cycle, so students actually received an average of ten minutes per day of microcomputer drill and practice.

Work with the microcomputer replaced a portion of the work done by the 3TI class using pencil and paper and chalkboard. Students in the 3CAI group completed only about two thirds as much traditional drill and practice as did the 3TI group.

The *Milliken Math Sequences* software is a commercially available microcomputer-assisted instruction series designed for drill and practice in mathematics. It has been widely employed by public schools during the past five years. The program package includes a teacher's manual and twelve floppy disks. Each disk deals with a separate program component or sequence; the twelve sequences include number readiness, addition, subtraction, multiplication, division, fractions, decimals, measurement formulas, laws of arithmetic, integers, percents, and equations.

A management program on each disk allows the teacher to set the beginning and ending difficulty level for each student, the number of problems to be presented at each level, and the level of achievement required to proceed to a higher level.

In the 3CAI class, only the addition, subtraction, and multiplication sequence disks were employed. To use the program, students accessed the assignment set for them by the teacher by entering their name and password into the microcomputer via the keyboard. Students were then presented with one problem at a time. Students entered their answers and were given immediate feedback for their response. Problems were presented in vertical, horizontal, and missing number formats.

Progress for each student was monitored by the disk-based management program. When students successfully completed 80 percent or more of the problems at an assigned level, they were moved to the next higher level. If they obtained more than 60 percent correct--but less that 80 percent--they repeated the level of difficulty, but with different problems being generated. When students obtained fewer than 60 percent correct responses, their program was lowered one level of difficulty. Table 1 lists the curriculum topics covered and the presentation mode used for the grade 3 treatments.

Table 1: Comparison of Curriculum Content for Groups 3TI and 3CAI

	Drill and Practice Mode	
Curriculum Topic	*3TI*	*3CAI*
Addition	Traditional[a]	CAI[b]
Subtraction	Traditional	CAI
Multiplication	Traditional	CAI
Measurement	Traditional	Traditional
Numeration	Traditional	Traditional
Fractions	Traditional	Traditional
Geometry	Traditional	Traditional

[a]Drill and practice using paper and pencil, chalkboard, and oral games
[b]Drill and practice using microcomputer-assisted instruction for ten minutes per day

Grade 5 Traditional Mathematics Instruction (5TI)

Students in the 5TI group were taught mathematics using the instructional delivery traditionally used by the teacher. Mathematics classes were scheduled for forty-five minutes each day.

The textbook used was *Holt Mathematics System* (Holt, Reinhardt and Winston 1980). At the beginning of each period, the teacher taught a lesson of twenty to twenty-five minutes dealing with new work or reviewing concepts previously taught. This was followed by drill-and-practice time during which students did problems from the textbook or from alternative book sources using either pencil and paper or the chalkboard. The teacher occasionally played oral math drill games with the students.

Grade 5 Adjunct Microcomputer-Assisted Mathematics Instruction (5CAI)

Mathematics instruction for this group was provided by the same teacher who taught the 5TI group. This teacher was provided with two hours of instruction in use of microcomputers for instruction and had previously taken a course in BASIC programming. Instruction was essentially the same as that for the 5TI group, though with one major exception. Each student received, during the forty-five-minute daily mathematics period, ten minutes of mathematics drill and practice on three out of every four days and fifteen minutes on the fourth day using a microcomputer and the Milliken Math Sequence software (Milliken Publishing Company 1980). Each student averaged 11.25 minutes per day of microcomputer-assisted instruction. Students in the 5CAI group completed only about two thirds as much traditional drill and practice as did the 5TI group.

The adjunct CAI with this group proceeded in the same manner as that described for the 3TI group, with two exceptions:

First, sequences used with the 5CAI group were multiplication, division, fractions, decimals, percents, and measurement formulas.

Second, students were required to obtain 90 percent correct responses to proceed to the next higher level in multiplication and division. They dropped one level with less than 70 percent correct and repeated the level if they obtained at least 70 percent but less than 90 percent correct.

With the other four sequences, a correct answer rate of 70 percent was required to proceed to the next higher level, and students dropped to a lower level if they achieved less than 30 percent correct. If they obtained 30 percent correct, but less than 70 percent, they repeated the problem level. Table 2 shows the curriculum topics covered and the presentation mode used for the grade 5 treatments.

Table 2: Comparison of Curriculum Content for Groups 5TI and 5CAI

	Drill and Practice Mode	
Curriculum Topic	*5TI*	*5CAI*
Multiplication	Traditional[a]	CAI[b]
Division	Traditional	CAI
Fractions	Traditional	CAI
Decimals	Traditional	CAI
Percents	Traditional	CAI
Measurement formulas	Traditional	CAI

[a]Drill and practice using paper and pencil, chalkboard, and oral games
[b]Drill and practice using microcomputer-assisted instruction for 11.25 minutes per day

Measurement Instruments

Paper and pencil tests were used in the pre- and post-tests of mathematics achievement, mathematics attitude, and computer literacy.

Mathematics Achievement

Students were tested before and after the treatments with the mathematics subtests of the Canadian Tests of Basic Skills (CTBS), Multilevel Edition, Form 5 (Hieronymous and others 1981). The subtests were as follows:

1. Mathematics Computation measured students' ability to compute using the four basic operations of addition, subtraction, multiplication, and division.
2. Mathematics Concepts measured students' understanding of the logic of the computational process and computational algorithms.

3. Mathematics Problem Solving measured students' ability to apply knowledge in solving numerical problems.

Total mathematics scores were also compiled. These scores were directly based on the three subtest scores.

The number of items in each subtest varied with the grade level of the students tested. Grade 3 students completed level 9 of each subtest; grade 5 students completed level 11 of each subtest.

Reliability of the CTBS is reported using the Kuder-Richardson Formula 20. National reliability coefficients are as follows:

	r Level 9	r Level 11
Mathematics Computation	.87	.93
Mathematics Concepts	.84	.82
Mathematics Problem Solving	.79	.82
Total Mathematics	.92	.93

Mathematics Attitude

Students were tested before and after treatments with the Survey of School Attitudes (SSA)--Form A (Hogan 1975). The SSA is designed to measure student reactions to four major areas of the school curriculum: reading, mathematics, science, and social studies. The sixty Likert-type items of the SSA are presented in cyclic fashion through the four scales to avoid response set through proximity. Students are asked to indicate how well they like or do not like to do the activity shown by marking "like," "not sure or don't care," or "dislike."

Grade 3 students completed the primary level of the test with the examiner reading each question. Grade 5 students completed the intermediate level of the test by reading and responding to each item. Only scores for the mathematics subscale were used in the data analysis.

Test reliability is reported using split-half reliability coefficients corrected by the Spearman-Brown Formula. National reliability coefficients for the SSA Mathematics Subscale are .89 for both the primary and intermediate levels.

Computer Literacy

Students were tested before and after treatments with the Computer Literacy Test (CLT), Grade 4 (Northwest Regional Educational Laboratory 1984).

The Computer Literacy Test is a forty-item multiple-choice test designed to measure students' ability to:

1. interact with a computer and/or other electronic devices

2. explain the functions and uses of a computer system
3. utilize systematic processes in problem-solving
4. appraise the impact of computer technology in today's society

Based on a field sample of 904 students, split-half reliability of the test is .70.

Costs

An accounting of the costs of adjunct microcomputer-assisted mathematics instruction as compared to traditional mathematics instruction was completed for this study. Costs of each intervention were tabulated as the project proceeded, and the final cost of each intervention was determined by developing a cost-resource spreadsheet.

Cost Ingredients

Separate sheets were constructed for costs of the following ingredients:

1. Personnel
   - Teacher salary and benefits
   - Program management
   - Supervision costs
2. Facilities and renovations
   - Classroom
   - Furniture
3. Equipment and materials
   - Textbooks
   - Microcomputer hardware
   - Microcomputer software
4. Other costs
   - Training
   - Energy

A cost was then assigned to each ingredient.

Cost Resources

Costs incorporated two annualization factors: (1) lifetime of resources--a method to account for the expected life of each resource; and (2) interest--to account for the forgone income on each investment that could have been realized if funds had been invested at a given interest rate instead of being used to purchase the resource.

Levin's (1983) method for annualizing the cost of an ingredient is to compute its annual cost by considering depreciation and the interest on remaining or undepreciated value.

A 9.25 percent interest rate was selected as the annual interest that could have been received by the school division during the project. Annualization factors based on 9.25 percent interest were used in this study. To use the factors, one need only multiply the appropriate annualization factor by the replacement cost of the ingredient to obtain the annual cost. The lifetime and annualization factors for facilities and equipment resources considered in this study are given in table 3. Lifetimes of microcomputer hardware and software were obtained by surveying six experts in the field of educational microcomputing.

Table 3: Lifetime and 9.25 Percent Annualization Factors for Facilities and Equipment Resources

	Values	
Resources	*Lifetime (Years)*	*Annualization Factors*[a]
Classrooms	33	.0978
Furniture	20	.1115
Textbooks	5	.2588
Microcomputer Hardware	8	.1824
Microcomputer Software	4	.3104

[a]Annualization factors for an annual interest rate of 9.25 percent.

All costs used in this study were based on the concept of "opportunity costs"--the value of resources in their best alternative use. Thus, additional time spent by personnel in one treatment that was not required by another treatment was considered to be an additional cost.

Cost Effectiveness

The cost-effectiveness of each intervention for effecting mathematics achievement was calculated. This was done by calculating the following ratio for each achievement outcome:

$$\text{Cost-effectiveness} = \frac{C}{E}$$

where C is the cost per student of the treatment
and E is the effectiveness of the treatment as indicated by the mean change in achievement test score.

Notably, the lower the cost-effectiveness value obtained by this ratio, the more cost-effective the intervention.

Converted grade equivalent scores were used in this analysis, rather than raw scores, so that the cost per month of gain in total mathematics for each group could be estimated.

Cost Utility

A cost-utility analysis was carried out using structured interviews of school board members. Each member of the division board of education was interviewed to determine the relative utility he or she placed on students' mathematics achievement, attitude toward mathematics, and computer literacy. The average utility value of the board was then calculated and used in the cost utility analysis. This interview-based approach followed procedures advocated by Stokey and Zeckhauser (1978) and Levin (1983).

The cost utility of each treatment was calculated by applying the following formula:

$$\text{Cost utility} = \frac{C}{(X*UX) + (Y*UY) + (Z*UZ)}$$

where C is the cost per student of the treatment
X is the mean change in achievement test score
Y is the mean change in mathematics attitude test score
Z is the mean change in computer literacy test score
UX is the utility of X as assessed by interviewees
UY is the utility of Y as assessed by interviewees
UZ is the utility of Z as assessed by interviewees

One problem researchers encounter when attempting to combine outcomes for analysis is that of converting different outcome measures to a common metric. In this study, all raw scores were converted to percentile ranks. These values were readily available for the Canadian Tests of Basic Skills (CTBS) and the Survey of School Attitudes (SSA). However, no such percentile norms were available for the Computer Literacy Test. Percentiles for this test were calculated from the raw scores of 903 students who had taken the test. These scores were supplied by the test publisher (Northwest Regional Educational Laboratory) as a norming sample.

Chapter 3

RESULTS

Results are reported in the following five sections:

1. Analysis of Effects
2. Analysis of Costs
3. Cost-Effectiveness Analysis
4. Cost-Utility Analysis
5. Sensitivity Analysis

Each of these sections compares adjunct microcomputer-assisted mathematics instruction with traditional mathematics instruction.

Analysis of Effects

The effects of microcomputer-assisted instruction compared with more traditional mathematics instruction were assessed through the six measures described earlier: Canadian Tests of Basic Skills (CTBS) Mathematics Computation Subscale, CTBS Mathematics Concepts Subscale, CTBS Mathematics Problem Solving Subscale, CTBS Total Mathematics, Survey of School Attitudes Mathematics Subscale, and the Computer Literacy Test. Results from these measures are discussed in the following subsections.

Mathematics Computation

Mean pretest and posttest scores for the four treatment groups on the CTBS Mathematics Computation Subscale are shown in table 4. The basic data presented in the table are based on raw scores, but mean grade-placement scores for the four groups are also included as more familiar points of reference. The adjusted mean raw scores reported in table 4 are derived from two analyses of covariance that were performed separately for the grade 3 and grade 5 students. These analyses showed that the grade 3 CAI students scored significantly higher on the posttest than did the grade 3 TI students ($F[1,38] = 5.96$, $p < .05$) but that the grade 5 CAI students did not. The analyses of covariance demonstrated no significant interaction effects.

Mathematics Concepts

Mean pretest and posttest scores for the four treatment groups on the CTBS Mathematics Concepts subscale are shown in table 5. As before, the data presented in the table are based on raw scores, but mean grade-placement scores for the four

Table 4: Mathematics Computation Mean Scores for Grades 3 and 5

Measure	*Group*			
	3TI (n=21)	*3CAI (n=20)*	*5TI (n=19)*	*5CAI (n=19)*
Pretest				
Mean raw scores	19.57	16.80	25.11	24.63
Raw score standard deviations	6.19	5.87	6.05	7.45
Mean grade placements	3.46	3.21	5.39	5.28
Posttest				
Mean raw scores	22.67	25.50	29.84	31.68
Raw score standard deviations	8.37	6.17	10.23	6.47
Mean grade placements	3.74	4.00	6.02	6.20
Adjusted Means	21.70	26.52	29.63	31.90
Significance	$p < .05$		n.s.	

groups are also included. The adjusted mean raw scores reported in table 5 are derived from two analyses of covariance that were performed separately for the grade 3 and grade 5 students. These analyses showed that the grade 3 CAI students did not score significantly higher on the Mathematics Concepts posttest than did the grade 3 TI students but that the grade 5 CAI students did score significantly higher on the posttest than did the grade 5 TI students ($F[1,35] = 4.96$, $p < .05$). The analyses of covariance demonstrated no significant interaction effects.

Table 5: Mathematics Concepts Mean Scores for Grades 3 and 5

Measure	*Group*			
	3TI (n=21)	*3CAI (n=20)*	*5TI (n=19)*	*5CAI (n=19)*
Pretest				
Mean raw scores	15.29	14.75	20.47	19.11
Raw score standard deviations	5.87	5.37	5.45	4.37
Mean grade placements	3.39	3.30	5.56	5.33
Posttest				
Mean raw scores	16.95	17.60	24.42	25.42
Raw score standard deviations	5.09	5.31	8.76	4.53
Mean grade placements	3.64	3.73	6.30	6.38
Adjusted Means	16.78	17.78	23.61	26.23
Significance	n.s.		$p < .05$	

Mathematics Problem Solving

Mean pretest and posttest scores for the four treatment groups on the CTBS Mathematics Problem Solving Subscale are shown in table 6. The data presented are based on raw scores, but mean grade-placement scores for the four groups are also included. The adjusted mean raw scores reported in table 6 are derived from two analyses of covariance that were performed separately for the grade 3 and grade 5 students. These analyses showed that the grade 3 CAI students did not score significantly higher on the Mathematics Problem Solving posttest than did the grade 3 TI students but that the grade 5 CAI students did score significantly higher on the posttest than did the grade 5 TI students ($F[1,35] = 4.55$, $p < .05$). The analyses of covariance demonstrated no significant interaction effects.

Table 6: Mathematics Problem-Solving Mean Scores for Grades 3 and 5

	Group			
Measure	*3TI (n=21)*	*3CAI (n=20)*	*5TI (n=19)*	*5CAI (n=19)*
Pretest				
Mean raw scores	11.52	11.00	16.47	15.53
Raw score standard deviations	4.27	4.58	6.25	5.21
Mean grade placements	3.44	3.46	5.63	5.33
Posttest				
Mean raw scores	13.29	13.30	17.42	19.00
Raw score standard deviations	3.64	5.42	6.77	5.27
Mean grade placements	3.80	3.75	5.76	6.04
Adjusted Means	13.12	13.48	17.01	19.41
Significance	n.s.		$p < .05$	

Total Mathematics

Mean pretest and posttest scores for the four treatment groups on the CTBS Total Mathematics are shown in table 7. The data presented are based on raw scores, but mean grade-placement scores for the four groups are also included. The adjusted mean raw scores reported in table 7 are derived from two analyses of covariance that were performed separately for the grade 3 and grade 5 students. These analyses showed that the grade 3 CAI students scored significantly higher on the Total Mathematics posttest than did the grade 3 TI students ($F[1,38] = 5.91$, $p < .05$) and that the grade 5 CAI students scored significantly higher on the posttest than did the grade 5 TI students ($F[1,35] = 10.08$, $p < .05$). The analyses of covariance also demonstrated a significant interaction effect (treatment group X covariate) among the grade 5 students.

Table 7: Total Mathematics Mean Scores for Grades 3 and 5

Measure	*Group*			
	3TI (n=21)	*3CAI (n=20)*	*5TI (n=19)*	*5CAI (n=19)*
Pretest				
Mean raw scores	46.38	42.55	62.05	59.26
Raw score standard deviations	13.41	12.71	15.41	14.70
Mean grade placements	3.42	3.29	5.53	5.32
Posttest				
Mean raw scores	52.90	56.40	71.68	76.11
Raw score standard deviations	14.63	15.15	24.79	14.33
Mean grade placements	3.71	3.86	6.03	6.20
Adjusted Means	51.20	58.19	69.99	77.80
Significance	$p < .05$		$p < .05$	

Mathematics Attitudes

Mean pretest and posttest scores for the four treatment groups on the Survey of School Attitudes Mathematics Subscale are shown in table 8. The adjusted mean raw scores reported in the table are derived from two analyses of covariance that were performed separately for the grade 3 and grade 5 students. These analyses showed no significant differences for either grade. Also the analyses of covariance demonstrated no significant interaction effects.

Table 8: Survey of School Attitudes Mean Scores for Grades 3 and 5

Measure	*Group*			
	3TI (n=21)	*3CAI (n=20)*	*5TI (n=19)*	*5CAI (n=19)*
Pretest				
Mean raw scores	17.24	17.50	18.32	15.32
Raw score standard deviations	7.48	6.41	7.27	7.08
Posttest				
Mean raw scores	20.71	22.15	18.95	19.32
Raw score standard deviations	7.71	6.22	7.11	8.04
Adjusted Means	20.80	22.06	17.67	20.59
Significance	n.s.		n.s.	

Computer Literacy

Mean pretest and posttest scores for the four treatment groups on the Computer Literacy Test are shown in table 9. The adjusted mean raw scores reported in the table are derived from two analyses of covariance that were performed separately for the grade 3 and grade 5 students. These analyses showed that the grade 3 CAI students scored significantly higher on the Computer Literacy posttest than did the grade 3 TI students ($F[1,38] = 16.27$, $p < .05$) and that the grade 5 CAI students scored significantly higher on the posttest than did the grade 5 TI students ($F[1,35] = 11.69$, $p < .05$). The analyses of covariance demonstrated no significant interaction effects.

Table 9: Computer Literacy Test Mean Scores for Grades 3 and 5

	Group			
Measure	*3TI (n=21)*	*3CAI (n=20)*	*5TI (n=19)*	*5CAI (n=19)*
Pretest				
Mean raw scores	20.00	18.70	21.79	20.95
Raw score standard deviations	3.48	4.22	2.90	3.88
Posttest				
Mean raw scores	20.24	23.30	22.79	25.11
Raw score standard deviations	3.40	4.07	2.68	3.33
Adjusted Means	19.86	23.70	22.57	25.33
Significance	$p < .05$		$p < .05$	

Analysis of Costs

Cost data were collected for each of the four treatment groups (3TI, 3CAI, 5TI, 5CAI). The ingredients for each treatment are specified in chapter 3. A cost was determined for each ingredient, and these costs were then totaled. All costs reported in this study are in Canadian dollars. (At the time of the study one Canadian dollar was equal to .739 U.S. dollars. Readers who are so interested may use this equation to translate the cost figures in this report to U.S. dollars.)

Table 10 summarizes the ingredients and their costs for groups 3TI and 3CAI, the additional costs for 3CAI over 3TI, and the percentage of the total additional 3CAI costs for each ingredient. The table shows that the cost per student per day for group 3CAI was twenty-four cents greater than for group 3TI.

Table 10: Comparison of Project Costs by Ingredients Category for Groups 3TI and 3CAI

	Group			
Ingredient	*3TI Cost*	*3CAI Cost*	*Additional Cost of CAI*	*Percent of Total Additional CAI Cost*
Personnel	$2,171	$2,264	$93	26.88%
Facilities & Renovations	$389	$390	$1	0.29%
Equipment & Materials	$106	$263	$157	45.38%
Other Costs	$45	$140	$95	27.45%
Total	$2,711	$3,057	$346	100.00%
Cost/Student	$129	$153	$24	
Additional cost of CAI per student per day			$0.24[a]	

[a]Total additional cost of CAI ($346)/number of students in 3CAI (20)/71 days
Note: Costs are in 1985 Canadian dollars.

Table 11 shows the annual costs projected for both grades 3 and 5 under the assumption that four fifty-five-minute mathematics periods per day would be provided to about twenty students in each period for 197 school days. These costs were projected assuming that roughly the same procedures used in this study would be followed in presenting microcomputer-assisted mathematics instruction and that the students would average about ten minutes per day of direct microcomputer interaction.

As the table shows, the increased annual costs projected for adjunct microcomputer-assisted mathematics instruction in grade 3 would be $3,010, or an increase of 9.59 percent over traditional instruction. Table A-1 in Appendix A provides a more complete accounting of the costs for traditional mathematics instruction for grade 3 students in this study, and table A-2 provides a more complete accounting of the costs for the grade 3 microcomputer-assisted instruction.

As table 11 also shows, in grade 5 the increased annual costs projected for adjunct microcomputer-assisted mathematics instruction would be $4,312, or an increase of 8.97 percent over the annual costs projected for traditional mathematics instruction. Table A-3 in Appendix A provides a more complete accounting of the costs for traditional mathematics instruction for grade 5 students in this study, and table A-4 provides a more complete accounting of the costs for the grade 5 microcomputer-assisted instruction.

Table 11: Total Annual Costs Projected for Grades 3 and 5 Mathematics Instruction[a]

	Group			
Measure	*3TI*	*3CAI*	*5TI*	*5CAI*
Annual Cost	$31,379	$34,389	$48,094	$52,406
Additional Cost of CAI[b]	$3,010		$4,312	
Percent Increase	9.59%		8.97%	

[a]Projections assume four 55-minute periods of mathematics instruction provided to 20 students in each period for 197 school days.
[b]Increased annual costs projected for adjunct microcomputer-assisted mathematics instruction.
Note: Costs are in 1985 Canadian dollars.

Table 12 summarizes the ingredients and their costs for groups 5TI and 5CAI, the additional costs for 5CAI over 5TI, and the percentage of the total additional 5CAI costs for each ingredient. The table shows that the cost per student per day for group 5CAI was thirty cents greater than for group 5TI.

Table 12: Comparison of Project Costs by Ingredients Category for Groups 5TI and 5CAI

Ingredient	*5TI Cost*	*5CAI Cost*	*Additional Cost of CAI*	*Percent of Total Additional CAI Cost*
Personnel	$2,941	$3,084	$143	35.57%
Facilities & Renovations	$318	$319	$1	0.25%
Equipment & Materials	$108	$249	$141	35.07%
Other Costs	$37	$154	$117	29.10%
Total	$3,404	$3,806	$402	100.00%
Cost/Student	$179	$200	$21	
Additional cost of CAI per student per day			$0.30[a]	

[a]Total additional cost of CAI ($402)/number of students in 5CAI (19)/71 days
Note: Costs are in 1985 Canadian dollars.

Cost-Effectiveness Analysis

Cost-effectiveness analysis was carried out to determine the cost per unit of achievement gain under each treatment. Cost per student from the analysis of costs and mean grade-placement scores for CTBS Total Mathematics from the analysis of effects were used in the cost-effectiveness analysis.

Table 13 shows the mean months of grade-placement gain in CTBS Total Mathematics for each treatment group. These means are based on the scores presented in table 7, the cost per student in this study (based on costs presented in tables 10-11), and the cost per month of gain per student. The latter values were calculated using the formula for cost-effectiveness presented earlier in this paper. As table 13 shows, the cost of producing each month of achievement gain in CTBS Total Mathematics for both grade 3 and grade 5 was lower using microcomputer-assisted mathematics instruction than it was using traditional mathematics instruction. This cost was 41 percent less in grade 3 and 38 percent less in grade 5. On this basis, the analysis indicated that the microcomputer-assisted instruction was the cost-effective alternative of choice for both grades.

Table 13: Total Mathematics Grade Placement Gains, Costs per Student, and Costs per Month of Gain

	Group			
Measure	*3TI (n=21)*	*3CAI (n=20)*	*5TI (n=19)*	*5CAI (n=19)*
Mean Grade Placement Gains in Months	2.86	5.70	4.94	8.89
Cost per Student	$129.06	$152.81	$179.15	$200.28
Cost per Month of Grade Placement Gain per Student	$45.13	$26.81	$36.27	$22.53

Note: Costs are in 1985 Canadian dollars.

Cost-Utility Analysis

A cost-utility analysis was carried out to include in the cost-effectiveness considerations the relative utilities that the school board would assign to gains in total mathematics achievement, attitudes toward mathematics, and computer literacy. These utilities were obtained through the interview process described earlier. Percentiles based on a single norming period provided a metric common to all three measurements used for this cost-utility analysis. These percentiles, weighted by the utilities obtained from the school board members, were combined with the costs determined for traditional instruction and microcomputer-assisted instruction to determine cost-utilities using the formula described earlier.

The results of this analysis are shown in table 14, which presents pretest and posttest percentile scores, gains, utilities, and cost-utilities for the four treatment groups (3TI, 3CAI, 5TI, and 5CAI) included in the study. In this context, cost-utility may be interpreted as the cost to obtain one unit of combined outcome gain weighted by the utilities assigned to mathematics achievement, mathematics attitude, and computer literacy by the school board. As the table shows, these utilities were 10.00, 8.29, and 10.86, respectively. The cost-utility of microcomputer-assisted mathematics instruction was 55 percent better than the cost-utility of traditional instruction for grade 3 and 64 percent better for grade 5. On this basis, the analysis indicated that microcomputer-assisted mathematics instruction was the cost-utility alternative of choice for both grades.

Table 14: Mean Percentile Scores and Cost Utilities for Grades 3 and 5

Measure	*Group*			
	3TI (n=21)	*3CAI (n=20)*	*5TI (n=19)*	*5CAI (n=19)*
Pretest				
CTBS Math[a]	46.19	40.05	52.47	47.32
SSA Math[b]	38.57	38.05	54.53	42.63
Computer Literacy[c]	57.95	48.75	72.53	64.11
Posttest				
CTBS Math	57.52	61.70	65.37	74.05
SSA Math	53.38	58.90	56.53	59.00
Computer Literacy	60.38	77.15	79.00	88.26
Gain				
CTBS Math (Utility = 10.00)	11.33	21.65	12.90	26.73
SSA Math (Utility = 8.29)	14.81	20.85	2.00	16.37
Computer Literacy (Utility = 10.86)	2.43	28.40	6.47	24.15
Cost Utility[d]	$0.49	$0.22	$0.83	$0.30

[a]Canadian Tests of Basic Skills Total Mathematics percentiles
[b]Survey of School Attitudes Mathematics Subscale percentiles
[c]Computer Literacy Test percentiles
[d]Cost per unit of combined outcome gains weighted by utilities obtained from school board members
Note: Costs are in 1985 Canadian dollars.

Sensitivity Analysis

The assumptions underlying a study such as this are necessarily imperfect. It is important to see how robust the results of the analyses are if the assumptions change. Four questions appeared to be of particular interest:

1. If personnel costs increase by 5 percent per year and hardware and software costs decline by 10 percent per year, how would the pattern of costs and cost-effectiveness change after a five-year period?
2. What would be the effect on the cost of microcomputer hardware if it were annualized over six rather than eight years?
3. At what minimum level of mathematics achievement does microcomputer-assisted mathematics instruction become more cost-effective than traditional mathematics instruction?
4. If mathematics achievement were the same for both microcomputer-assisted mathematics instruction and traditional mathematics instruction, would microcomputer-assisted instruction remain the cost-utility alternative of choice?

Changes in Personnel and Hardware Costs

Table 15 compares the costs that would be incurred by groups 3TI and 3CAI after five years if personnel costs increased by 5 percent per year and microcomputer hardware and software costs decreased by 10 percent per year. At least three results from the table are notable:

Table 15: Project Costs for Grade 3 after Five Years Assuming 5 Percent Annual Increases in Personnel Costs and 10 Percent Annual Decreases in Hardware and Software Costs

Ingredient	*3TI Cost*	*3CAI Cost*	*Additional Cost of CAI*	*Percent of Total Additional CAI Cost*
Personnel	$2,771	$2,889	$118	33.91%
Facilities & Renovations	$389	$390	$1	0.29%
Equipment & Materials	$106	$215	$109	31.32%
Other Costs	$45	$165	$120	27.45%
Total	$3,311	$3,659	$348	100.00%
Additional cost of CAI per student per day			$0.25[a]	

Note: Costs are in 1985 Canadian dollars.

1. After five years the additional cost of adjunct microcomputer-assisted mathematics instruction over traditional mathematics instruction would be $348 rather than the present $346 shown in table 10. The additional cost per student per day for adjunct CAI would be twenty-five cents rather than the present twenty-four cents. Evidently the additional cost of adjunct microcomputer-assisted instruction over traditional instruction would remain fairly stable over a five-year period under the cost trends assumed for this analysis.
2. While the total project costs of traditional mathematics instruction would rise from $2,711 to $3,311, or 22.1 percent, the costs of adjunct microcomputer-assisted mathematics instruction would rise noticeably less, from $3,057 to $3,659, or 19.7 percent.
3. The percentage of additional costs of adjunct microcomputer-assisted mathematics instruction would rise for the personnel category and decline for the equipment and materials category, making these percentages almost equal.

Table 16 compares the costs that would be incurred by groups 5TI and 5CAI after five years if personnel costs increased by 5 percent per year and microcomputer hardware and software costs decreased by 10 percent per year. The results are similar to those for grade 3:

Table 16: Project Costs for Grade 5 after Five Years Assuming 5 Percent Annual Increases in Personnel Costs and 10 Percent Annual Decreases in Hardware and Software Costs

Ingredient	*3TI Cost*	*3CAI Cost*	*Additional Cost of CAI*	*Percent of Total Additional CAI Cost*
Personnel	$3,754	$3,936	$182	42.52%
Facilities & Renovations	$318	$319	$1	0.23%
Equipment & Materials	$108	$204	$96	22.43%
Other Costs	$37	$186	$149	34.81%
Total	$4,217	$4,645	$428	100.00%
Additional cost of CAI per student per day			$0.32	

Note: Costs are in 1985 Canadian dollars.

1. As in grade 3, the additional costs of adjunct microcomputer-assisted mathematics instruction appear to remain fairly stable under the personnel and microcomputer cost trends assumed here. The rising personnel costs for grade 5 would increase the additional costs of adjunct microcomputer-assisted mathematics instruction from thirty cents per student per day, as shown in table 11, to thirty-two cents per student per day--while total project costs would increase from $402 to $428.
2. Whereas the total project costs of traditional mathematics instruction would rise from $3,404 to $4,217, or 23.9 percent, the costs of adjunct microcomputer-assisted mathematics instruction would rise less, from $3,806 to $4,645, or 22 percent.
3. The percentage of additional costs for adjunct microcomputer-assisted mathematics instruction due to personnel costs would be double the percentage of additional costs due to equipment and materials. At the present time, as shown in table 11, these costs are almost equal.

Hardware Annualized over Six Years

To determine the effect of annualizing microcomputer hardware costs over six rather than eight years, one need only multiply the initial cost of hardware ($6,102, as shown in the Appendix) by the appropriate annualization factor of .2246 (assuming six years at 9.25 percent interest). The resulting annual cost is $1,370.51 for six-year annualization compared with $1,112.74 for eight-year annualization. The cost of hardware for the grade 3 project would then be $123.49 rather than $100.26. The cost of hardware for the grade 5 project would then be $98.79 rather than $80.21.

These increases would not change the results of the cost-effectiveness and cost-utility analyses already performed. For that matter, the annual maintenance cost of each microcomputer might be lower over a six-year-period, thereby offsetting the additional cost incurred by annualizing the useful life of each microcomputer over six rather than eight years.

Achievement Needed for Cost-Effectiveness

Straightforward ratios of costs and effectiveness can be used to determine the level of mathematics achievement needed to make adjunct microcomputer-assisted mathematics instruction more cost-effective than traditional mathematics instruction. Given per student project costs of 3TI ($129.06 from table 10) and 3CAI ($152.81 from table 10) and a mean achievement gain of 2.89 months for 3TI, a mean achievement gain of at least 3.39 months would be necessary to make adjunct microcomputer-assisted mathematics instruction more cost effective than traditional mathematics instruction. Stated another way, for the adjunct microcomputer-assisted instruction to be more cost effective, it would need to

produce an average of at least 0.50 (3.39 - 2.89) months more gain than traditional mathematics instruction. In this project, the additional gain was 2.84 (5.70 - 2.86) months.

Given per student project costs of 5TI ($179.15 from table 11) and 5CAI ($200.28 from table 11), and a mean achievement gain of 4.94 months for 5TI, a mean achievement gain of at least 5.52 months would be necessary to make adjunct microcomputer-assisted mathematics instruction more cost effective than traditional mathematics instruction. Stated another way, for the adjunct microcomputer-assisted instruction to be more cost effective, it would need to produce an average gain of at least .58 (5.52 - 4.94) months more gain than traditional mathematics instruction. In this project, the additional gain was 3.95 (8.89 - 4.94) months.

Cost Utility with No Achievement Differences

In this analysis, it was assumed that the average percentile rank gain in CTBS mathematics achievement for all students at a given grade level was attained by each group. This average was 16.36 for grade 3 and 19.82 for grade 5. Cost utility was then calculated using these average gains, the actual costs, the utilities obtained from the school board members (shown in table 14), the percentile rank gains for attitude to mathematics (SSA Math), and the percentile rank gains for computer literacy. These values and the resulting cost-utility values are shown in table 17. As the table shows, adjunct microcomputer-assisted mathematics instruction would continue to have more cost utility in both grade 3 and grade 5 if total mathematics achievement were the same in both treatment groups.

Table 17: Mean Percentile Rank Gains for Grades 3 and 5

Measure	*Group*			
	3TI (n=21)	*3CAI (n=20)*	*5TI (n=19)*	*5CAI (n=19)*
CTBS Math[a] (Utility = 10.00)	16.36	16.36	19.82	19.82
SSA Math[b] (Utility = 8.29)	14.81	20.85	2.00	16.37
Computer Literacy[c] (Utility = 10.86)	2.43	28.40	6.47	24.15
Cost	$129.06	$152.81	$179.15	$200.28
Cost-Utility[d]	$0.41	$0.24	$0.63	$0.34

[a]Canadian Tests of Basic Skills Total Mathematics percentiles
[b]Survey of School Attitudes Mathematics Subscale percentile rank gain
[c]Computer Literacy Test percentile rank gain
[d]Cost per unit of combined outcome gains weighted by utilities obtained from school board members
Note: Costs are in 1985 Canadian dollars.

These sensitivity analyses are intended to be illustrative and relevant, but not comprehensive. Different analyses would need to be performed to answer questions important to other investigators and educational decision-makers.

Chapter 4

DISCUSSION OF RESULTS

Effects of Treatments

Grade 3 students in this study who used adjunct microcomputer-assisted mathematics instruction scored significantly higher in mathematics computation than did students who used traditional mathematics instruction. This result is consistent with the findings of previous evaluation studies that demonstrated significant beneficial effects of computer-assisted instruction on mathematics computation scores (Jamison and others 1976, Ragosta and others 1981, Steele and others 1984). Grade 5 students in this study who used adjunct microcomputer-assisted mathematics instruction scored about 8 percent higher than did students who used traditional mathematics instruction--a difference not considered significant.

Grade 5 students in this study who used adjunct microcomputer-assisted mathematics instruction scored significantly higher in mathematics concepts than did students who used traditional mathematics instruction. This finding is less common in the evaluation literature than is the previous one, but it is not without precedent (for example, Jamison and others 1976). Grade 3 students in this study who used adjunct microcomputer-assisted mathematics instruction scored about 6 percent higher than students who used traditional mathematics instruction; again, this difference was not considered significant.

Grade 5 students in this study who used adjunct microcomputer-assisted mathematics instruction scored significantly higher in mathematics problem-solving than did students who used traditional mathematics instruction. This finding is unusual for materials like the *Milliken Math Sequences*. Grade 3 students in this study who used adjunct microcomputer-assisted mathematics instruction scored about 3 percent higher than did students who used traditional mathematics instruction.

In short, the grade 3 students scored higher on mathematics computation, and the grade 5 students scored higher on mathematics concepts and problem-solving. To some extent this contrast may be an artifact of the procedures used in this study. The 5CAI group was split into two subgroups -- one of which used the computers in the room while the other received the teacher-presented portion of the lesson. Once these presentations were finished, the subgroups were switched. Thus, students in the 5CAI group may have had a more intense contact with the teacher because they were taught the material in smaller groups. The teaching of more conceptual material, such as mathematics concepts and problem-solving, may have benefited relatively more from this treatment than did the teaching of material emphasized by the *Milliken Math Sequences* and requiring more practice -- hence the significant differences favoring the 5CAI group for mathematics concepts and problem-solving and the lack of them for the 3CAI group. On the other hand, this

possibility does not explain why there should be no significant difference favoring the 5CAI group for mathematics computation.

Grade 3 and grade 5 students in this study who used microcomputer-assisted mathematics instruction scored significantly higher on total mathematics than did students who used traditional mathematics instruction. Taken with similar results from earlier studies (Jamison and others 1976, Steele and others 1984), this finding strongly supports the notion that adjunct microcomputer-assisted instruction enhances the mathematics skills of elementary school students.

Although scores on the Survey of School Attitudes toward mathematics were 6 percent higher for the grade 3 CAI students and 17 percent higher for the grade 5 CAI students, neither of these differences was statistically significant. The students apparently enjoyed using the microcomputer instruction, and it seemed reasonable to expect some measurable improvement in their attitudes toward mathematics. The findings from this study are fairly promising and indicate that later studies may be able to demonstrate significant improvements in attitudes toward mathematics as a result of introducing microcomputer-assisted instructions

As expected, students in both grades who were exposed to microcomputer-assisted instruction scored significantly higher on a test of computer literacy than did those not exposed to microcomputers. Apparently this exposure, even though it did not explicitly present instruction in computer literacy, provided students with some knowledge of computers. The knowledge received was primarily in areas of computer use and interaction rather than in systematic processes for problem-solving or in appraising the impact of computer technology on society.

The cost of adjunct microcomputer-assisted instruction in grade 3 was twenty-four cents per student per day greater than the cost of traditional instruction. The corresponding additional cost for grade 5 was thirty cents per student per day. Given these low values, the cost of providing adjunct microcomputer-assisted instruction of the sort used in this study may be small enough to appeal to many school boards making implementation decisions.

Given the annual costs projected from the costs observed in this study and shown in table 11, the per student per year cost of adjunct microcomputer-assisted instruction in grade 3 would be $37.63 greater than the cost of traditional instruction. The corresponding additional cost for grade 5 would be $53.90 per student per year. These projections were made assuming that the students receiving adjunct microcomputer-assisted instruction would average about ten minutes per day of direct microcomputer interaction. These costs can be compared, therefore, with the per student per year costs of $121 estimated by Levin and $119 estimated by Piele (Levin 1984) to provide ten minutes per day of computer-assisted instruction.

Notably, the annual costs projected from this study are about one-third to one-half of those estimated by Levin and by Piele. There are at least two reasons for these differences.

First, the CAI system considered by Levin and Piele (Levin 1984) is a laboratory-based intervention. The instruction takes place away from the regular classroom in a computer laboratory. Costs of providing the laboratory and the personnel to staff it account for almost one-half of the total costs of the CAI. With

the adjunct CAI approach used in this study there were no laboratory costs.

Second, the hardware in the model considered by Levin and Piele is more sophisticated and costly than the hardware used in this study. Levin's data applied to a time-shared minicomputer system and Piele's to a networked microcomputer system. Hardware costs in this study are for stand-alone microcomputers.

The distinction between Levin's computer instruction model and the model used in this study deserves some comment. A computer laboratory, such as the one considered by Levin and Piele, might operate without a classroom teacher, thereby lowering costs. However, providing students with ten minutes of CAI each day using the laboratory approach may actually consume twenty minutes or more of their time, depending on the proximity of the laboratory to the students' classroom. Further, elementary school students would need supervision by an adult on their way to and from the laboratory and in the laboratory itself. Finally, the twenty minutes or so that the students are out of the classroom is as likely to be a disruptive diversion for the classroom teachers as it is an opportunity to accomplish relevant tasks. It is unlikely that a laboratory approach will result in personnel cost savings. It may result in hardware and software savings, but useful trade-offs between laboratory-based and classroom-based CAI approaches must await consideration in later studies.

Cost Effectiveness

Cost-effectiveness analysis was carried out to determine whether adjunct microcomputer-assisted mathematics instruction or traditional instruction would provide the lowest cost per unit of achievement gain in CTBS Total Mathematics. In grade 3, the cost of providing each month of gain in CTBS Total Mathematics was found to be $45.13 with traditional instruction and $26.81 with adjunct microcomputer-assisted instruction. In grade 5, the cost of providing each month of gain in CTBS Total Mathematics was found to be $36.27 with traditional instruction and $22.53 with adjunct microcomputer-assisted instruction. In this sense, adjunct microcomputer-assisted mathematics instruction was found to be more cost effective than traditional mathematics instruction in both grades. The microcomputer instruction cost slightly more to deliver, but the gains in achievement were proportionately much greater and made up for the extra cost by a factor exceeding five in grade 3 and a factor exceeding six in grade 5.

Cost Utility

Three basic outcomes were considered in the study: mathematics achievement, attitude toward mathematics, and computer literacy. When the utility values that members of the school board placed on each outcome were considered, adjunct microcomputer-assisted mathematics instruction was found to have more cost utility than traditional mathematics instruction in both grade 3 and grade 5. It is

interesting to note that the school board gave computer literacy a higher utility rating (10.86) than mathematics achievement (10.00), which in turn was given a higher utility rating than attitude toward mathematics (8.29).

The higher rating given to achievement than to attitude is not surprising, but the rating of computer literacy over mathematics achievement was not expected. One possible explanation is that educational decision-makers may believe they have more tools at their disposal for improving mathematics achievement than for improving computer literacy. They may place a greater value, therefore, on computer literacy achievement because it seems harder to come by.

Sensitivity

Sensitivity analyses provided the following information:

First, if personnel costs rise by 5 percent annually and microcomputer hardware and software costs decline by 10 percent annually, the additional cost of adjunct CAI over traditional instruction will be about the same in five years as it is now. This is important in that most other instructional costs are likely to increase by 25 to 30 percent over the next five years. Eventually, however, the effect of hardware and software costs on total costs will diminish as they occupy a smaller and smaller proportion of those total costs.

Second, annualizing the cost of microcomputer hardware over six rather than eight years increases the estimated cost of the hardware by about 20 percent. However, this annualization does not change the results of the cost-effectiveness or cost-utility analyses.

Third, to be cost-effective, adjunct microcomputer-assisted mathematics instruction needed to produce during the seventy-one-day project .50 more months of mathematics achievement gain in grade 3 and .58 more months in grade 5 than traditional mathematics instruction. Actual additional gains in the project were 2.84 months for grade 3 and 3.95 months for grade 5. Thus, even if the achievement gains suffered from diminishing returns in a longer intervention, those gains would have to be a great deal smaller before adjunct CAI would no longer be more cost-effective than traditional instruction.

And finally, when the school board's utilities were considered, adjunct microcomputer-assisted mathematics instruction would have been more cost-effective than traditional mathematics instruction even if there had been no difference in the mathematics achievement gains produced by the two treatments. This was due primarily to the high utility value placed on computer literacy by the board and the significant gains made in computer literacy by students exposed to adjunct microcomputer-assisted mathematics instruction.

Chapter 5

CONCLUSIONS

On the basis of the findings obtained in this study, the following conclusions can be drawn:

1. Students who were exposed to adjunct microcomputer-assisted mathematics instruction improved significantly more in mathematics than did students who were exposed to traditional mathematics instruction.
2. Students who were exposed to adjunct microcomputer-assisted mathematics instruction improved significantly more in computer literacy than did students who were exposed to traditional mathematics instruction.
3. There was no significant difference between adjunct microcomputer-assisted mathematics instruction and traditional mathematics instruction with respect to their effect on students' attitudes toward mathematics.
4. The cost of adjunct microcomputer-assisted instruction was lower than the estimated costs of laboratory-based CAI reported in an earlier study.
5. Adjunct microcomputer-assisted mathematics instruction was more cost-effective than traditional mathematics instruction for producing gains in mathematics achievement.
6. Adjunct microcomputer-assisted mathematics instruction was more cost-effective than traditional mathematics instruction when consideration was given to the utility values that the school board placed on students' attitudes toward mathematics and computer literacy compared to mathematics achievement.

This study investigated concepts and claims regarding CAI required in the *estimation* phase of the policy process. It also integrated a nonrational element (utility analysis) into the process and reduced uncertainty about options to enhance the *selection* phase of the policy process. Therefore, this study should provide useful information for boards considering implementation of computer-assisted instruction.

This study is not intended to be the final word on the costs, effects, and utility of microcomputer-assisted instruction. As Aggar and Goldstein (1971) pointed out, "One cannot construct a valid theory, whether of nuclear physics or of community educational politics, based on the kind of instant knowledge derived from a single piece of experimental research" (p. 36). We intend this study to be a useful contribution to this particular line of research. We also hope that other studies will follow.

APPENDIX

Table A-1: Ingredients and Costs of Adjunct Microcomputer-Assisted Mathematics Instruction for Group 3CAI

Table A-2: Ingredients and Costs of Traditional Mathematics Instruction for Group 3TI

Table A-3: Ingredients and Costs of Adjunct Microcomputer-Assisted Mathematics Instruction for Group 5CAI

Table A-4: Ingredients and Costs of Traditional Mathematics Instruction for Group 5TI

Table A-1: Ingredients and Costs of Adjunct Microcomputer-Assisted Mathematics Instruction for Group 3CAI

Ingredient	Initial Cost	Interest Rate	Lifetime of Asset	Annual Cost (4 55-Minute Periods/Day for 197 Days)		Project Cost (1 55-Minute Period/Day for 71 Days)
PERSONNEL						
Teacher costs						
Annual remuneration						
- Salary (197 days)	$22,969.00			$22,969.00	*	$2,069.54
- Additional benefits	$1,129.69			$1,129.69	*	$101.79
Program management						
- 2 hours @ $16.31	$32.62			$362.04	*	$32.62
Total teacher costs				$24,460.73	*	$2,203.95
Supervisor's salary						
2 hours @ $29.84				$662.36	*	$59.68
FACILITIES AND RENOVATIONS						
Classroom	$63,802.20	9.25%	33	$6,238.34	**	$374.72
Classroom furniture						
Teacher desk and chair	$360.00					
20 student desks @ $85.05	$1,701.00					
3 computer tables @ $44.00	$132.00					
Total furniture costs	$2,193.00	9.25%	20	$244.53	**	$14.69
EQUIPMENT AND MATERIALS						
Microcomputer hardware						
6 Apple IIe microcomputers @ $1,017.00	$6,102.00	9.25%	8	$1,112.74	*	$100.26
Maintenance of 6 Apple IIe microcomputers @ $70.00/year	$420.00			$420.00	*	$37.84

Microcomputer software					
6 Addition disks	$218.18				
6 Subtraction disks	$218.18				
6 Multiplication disks	$218.18				
1 Teacher's guide	$10.00				
Total software costs	$664.54	9.25%	4	$206.25 *	$18.58
Textbooks					
20 Textbooks @ $14.15	$283.00	9.25%	5	$292.92 ***	$105.57
Miscellaneous					
Extension cords, adapters, etc.	$50.00	9.25%	5	$12.94 *	$1.17
OTHER COSTS					
Training					
Teacher time - 2 hours @ $16.31	$32.62			$130.48 ***	$32.62
Supervisor time - 2 hours @ 29.84	$59.68			$59.68	$59.68
Energy					
Heating	$28.45			$273.53 **	$28.45
Electricity - Regular consumption	$16.42			$245.28 **	$16.42
- Microcomputer consumption (6 microcomputers X 100 watts X 4 hours X $ .0614 per KW hour)	$2.62			$29.08 *	$2.62
TOTAL COST				$34,388.85	$3,056.25

*Based on: (project cost) x (197 days/71 days) x (4 periods)
**Based on: (project cost) x (197 days/71 days) x (330 minutes/55 minutes)
***Based on: (project cost) x (197 days/71 days)
****Based on: (project cost) x (4 teachers)

Table A-2: Ingredients and Costs of Traditional Mathematics Instruction for Group 3TI

Ingredient	Initial Cost	Interest Rate	Lifetime of Asset	Annual Cost (4 55-Minute Periods/Day for 197 Days)		Project Cost (1 55-Minute Period/Day for 71 Days)
PERSONNEL						
Teacher costs						
Annual remuneration						
- Salary (197 days)	$22,969.00			$22,969.00	*	$2,069.54
- Additional benefits	$1,129.69			$1,129.69	*	$101.79
Total teacher costs				$24,098.69	*	$2,171.33
FACILITIES AND RENOVATIONS						
Classroom	$63,802.20	9.25%	33	$6,238.34	**	$374.72
Classroom furniture						
Teacher desk and chair	$360.00					
20 Student desks @ $85.05	$1,701.00					
Total furniture costs	$2,061.00	9.25%	20	$229.81	**	$13.80
EQUIPMENT AND MATERIALS						
Textbooks						
20 Textbooks @ $14.15	$283.00	9.25%	5	$292.92	***	$105.57
OTHER COSTS						
Energy						
Heating	$28.45			$273.53	**	$28.45
Electricity						
- Regular consumption	$16.42			$245.28	**	$16.42
TOTAL COST				$31,378.57		$2,710.29

*Based on: (project cost) x (197 days/71 days) x (4 periods)
**Based on: (project cost) x (197 days/71 days) x (330 minutes/55 minutes)
***Based on: (project cost) x (197 days/71 days)

Table A-3: Ingredients and Costs of Adjunct Microcomputer-Assisted Mathematics Instruction for Group 5CAI

Ingredient	Initial Cost	Interest Rate	Lifetime of Asset	Annual Cost (5 45-Minute Periods/Day for 197 Days)		Project Cost (1 45-Minute Period/Day for 71 Days)
PERSONNEL						
Teacher costs						
Annual remuneration						
- Salary (197 days)	$39,642.00			$39,642.00	*	$2,857.44
- Additional benefits	$1,166.05			$1,166.05	*	$84.05
Program management						
- 3 hours @ $27.62	$82.86			$1,149.54	*	$82.86
Total teacher costs				$41,957.59	*	$3,024.35
Supervisor's salary						
2 hours @ $29.84				$827.95	*	$59.68
FACILITIES AND RENOVATIONS						
Classroom	$63,802.20	9.25%	33	$6,238.34	**	$306.59
Classroom furniture						
Teacher desk and chair	$360.00					
20 Student desks @ $85.05	$1,701.00					
3 Computer tables @ $44.00	$132.00					
Total furniture costs	$2,193.00	9.25%	20	$244.53	**	$12.02
EQUIPMENT AND MATERIALS						
Microcomputer hardware						
6 Apple IIe microcomputers @ $1,017.00	$6,102.00	9.25%	8	$1,112.74	*	$80.21
Maintenance of 6 Apple IIe microcomputers @ $70.00/year	$420.00			$420.00	*	$30.27
Microcomputer software						
6 Decimal disks	$218.18					

6 Percent disks	$218.18					
6 Multiplication disks	$218.18					
6 Fraction disks	$218.18					
6 Division disks	$218.18					
6 Measurement disks	$218.18					
1 Teacher's guide	$10.00					
Total software costs	$1,319.08	9.25%	4	$409.40	*	$29.51
Textbooks						
20 Textbooks @ $14.45	$289.00	9.25%	5	$299.13	***	$107.81
Miscellaneous						
Extension cords, adapters, etc.	$50.00	9.25%	5	$12.94	*	$0.93
OTHER COSTS						
Training						
Teacher Time - 2 hours @ $27.62	$55.24			$276.20	***	$55.24
Supervisor Time - 2 hours @ 29.84	$59.68			$59.68		$59.68
Energy						
Heating	$28.45			$273.53	**	$23.28
Electricity - Regular consumption	$13.43			$245.28	**	$13.43
- Microcomputer consumption (6 microcomputers X 100 watts X 4 hours X $ .0614 per KW hour)	$2.62			$29.08	*	$2.62
TOTAL COST				$52,406.38		$3,805.63

*Based on: (project cost) x (197 days/71 days) x (5 periods)
**Based on: (project cost) x (197 days/71 days) x (330 minutes/45 minutes)
***Based on: (project cost) x (197 days/71 days)
****Based on: (project cost) x (5 teachers)

Table A-4: Ingredients and Costs of Traditional Mathematics Instruction for Group STI

Ingredient	Initial Cost	Interest Rate	Lifetime of Asset	Annual Cost (5 45-Minute Periods/Day for 197 Days)		Project Cost (1 45-Minute Period/Day for 71 Days)
PERSONNEL						
Teacher costs						
Annual remuneration						
- Salary (197 days)	$39,642.00			$39,642.00	*	$2,657.44
- Additional benefits	$1,166.05			$1,166.05	*	$84.05
Total teacher costs				$40,808.05	*	$2,941.49
FACILITIES AND RENOVATIONS						
Classroom	$63,802.20	9.25%	33	$6,238.34	**	$306.59
Classroom furniture						
Teacher desk and chair	$360.00					
20 Student desks @ $85.05	$1,701.00					
Total furniture costs	$2,061.00	9.25%	20	$229.81	**	$11.29
EQUIPMENT AND MATERIALS						
Textbooks						
20 Textbooks @ $14.45	$289.00	9.25%	5	$299.13	***	$107.81
OTHER COSTS						
Energy						
Heating	$28.45			$273.53	**	$23.28
Electricity						
- Regular consumption	$13.43			$245.28	**	$13.43
TOTAL COST				$48,094.14		$3,403.90

*Based on: (project cost) x (197 days/71 days) x (5 periods)
**Based on: (project cost) x (197 days/71 days) x (330 minutes/45 minutes)
***Based on: (project cost) x (197 days/71 days)

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